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980H2 Steel Mill Battery Box Redesign for Caterpillar Inc.

Grania Maeve VanHerwarde

Worcester Polytechnic Institute

Murtada Abdulhameed Al Darweesh

Worcester Polytechnic Institute

Pedro Jose Escuer Velasquez

Worcester Polytechnic Institute

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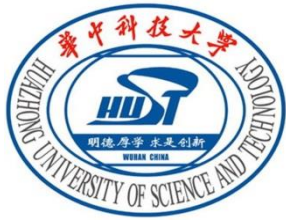
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980H2 Steel Mill Battery Box Redesign

A Major Qualifying Project Report
submitted to the faculty of
Worcester Polytechnic Institute
in partial fulfillment of the requirements
for the
Degree of Bachelor of Science
Submitted on August 15th, 2014



WPI

CATERPILLAR®

Contributors

WPI

Murtada Al Darweesh
Pedro Escuer
Grania VanHerwarde

HUST

Xiaoqian Wang
Dai Wei
Feng Zhou

Advisors

WPI – Prof Kevin Rong
WPI – Prof Amy Zeng
HUST – Prof Lingsong He

Sponsor

Dany Dong
Caterpillar Special
Applications Engineering

Abstract

Under Caterpillar, Inc. sponsorship, three WPI students and three HUST students collaborated to redesign the battery box of the 980H2 Steel Mill Application Wheel Loader to solve interferences and reduce cost. The team gathered design specifications and created an evaluation system using multiple criteria. The team achieved the goal and demonstrated cost reduction opportunities in the designs generated. Finally, ideas for the relocation of the lifting eyes were produced.

Acknowledgments

We would like to recognize several individuals who have supported our team during the past four months. Their assistance was vital to the success of this project.

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Lastly, we would like to acknowledge our Huazhong University of Science and Technology partners Wei Dai (David), Xiaoqian Wang (Anna), and Feng Zhou (Daniel), for their contributions to the project, helping us to adjust to Wuhan, teaching us about Chinese Culture and helping as our translators most of the times.

Authorship

Murtada Al Darweesh, Pedro Escuer, and Grania VanHerwarde all contributed to the research and writing of this report. Wei Dai, Xiaoqian Wang, and Feng Zhou main contribution were the different designs created. It is important to mention that all the six members of the team discussed and provided ideas in order to be designed. The following is a breakdown of how the report was written for this project.

Murtada Al Darweesh contributed to this report by writing the Introduction, and Chapter 4 & 6.

Pedro Escuer contributed to this report by creating the cover page of the report, writing Chapter 2 & 5, acknowledgements, and realizing the House of Quality. Mr. Escuer also contributed by organizing the slide shows for all presentations for this project.

Grania VanHerwarde contributed to this report by writing the Introduction, and Chapter 3 & 6. Ms. VanHerwarde was the main editor for content for the writing of this report. Lastly, she formatted the entire paper into a single cohesive document.

In addition to their individual contributions, Murtada Al Darweesh, Pedro Escuer, and Grania VanHerwarde all edited the paper for continuity as a group.

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Chapter 1: Introduction

Infrastructure development is a continuous process: new roads and bridges are being built in developing markets, while old structures are being replaced in developed areas. There is a need for raw materials as well, those that are mined and extracted from the earth in order to create the products we use every day. Caterpillar is a company satisfying those needs, and many more in the industrial goods sector of the diversified machinery industry. They are the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines, and diesel-electric locomotives.

Caterpillar is a Fortune 500 company with offices on every continent, excluding Antarctica. As such, Caterpillar employs approximately 118,500 people that work together to bring solutions to provide more sustainable and efficient products to their customers.

A company's values are the basis of the company; they define the company mission and strategy. Caterpillar's core values are Integrity, Excellence, Teamwork, and Commitment. These are written in the company Code of Conduct, which was first written in 1974 and last updated in 2010. Company strategy derives from following its values and the guidelines provided by the Code of Conduct. The base of Caterpillar's strategy is their values. Caterpillar's strategy revolves around three groups of people: their stockholders, customers, and their people or employees. Caterpillar seeks to deliver superior returns to investors, help their customers succeed, and attract and train the best talent in their employees.

During the past years China has been developing in an outrageous way. As a matter of fact, China is currently the second largest economy in the world, and is the largest manufacturer of goods. Additionally, its mining industry is one of the biggest and profitable of the world. According to data from the National Bureau of Statistics of China, China produced 34.24 million metric tons of 10 major non-ferrous metal products in 2011, up 10.6 percent year-on-year^[1]. Additionally China has a controlled production of 95% of the rare earth mineral mining ^[2]. Therefore, the Chinese mining industry is of great interest to any mining-related companies due the available business opportunities.

Caterpillar began operations in China in the early 1970s, but did not open its own manufacturing facilities there until around 1990. Once the company felt that the business was

stable, Caterpillar deployed its full business model in China. This included its different service offerings, such as Financial Services, Caterpillar Remanufacturing Services, Caterpillar Logistics Services, and Progress Rail. As mentioned before, the Chinese mining industry offers incredible business opportunities for companies such as Caterpillar. The company has created a large presence, not only in China but in the Asia-Pacific region as a whole. With approximately \$4,690 million in sales, the company is a leader in the Chinese mining and manufacturing industry.

To maintain its position as a leading manufacturer of industrial machinery, Caterpillar must continue to innovate on its products to stay ahead of the competition. However, when changes are made to products, sometimes the design no longer fits the needs of the customer. This project focuses on the 980H2 Steel Mill Battery Box Redesign. The original change was relatively simple: changing the material of the engine hood. However, this simple change from fiberglass, a lightweight material, to steel, a heavier material, requires other modifications in the design, as it limits the access underneath the hood. The battery box is one of the parts that is within the hood, and will no longer be easily accessible. Therefore, the battery box must be redesigned, or moved to another area in the vehicle to maintain the same amount of access. The job of our team is to find the best approach to redesign the battery box with minimal cost.

Chapter 2: Background

This chapter is a synthesis of the initial research conducted by the team to gain a better understanding of the project. This chapter begins with an introduction to our sponsor, Caterpillar, Inc. and will deduce what value our project will have for the company. Afterwards we take a closer look at the special application 980H Steel Mill Wheel Loader machine. In this section we will discover why a redesign is needed. Subsequently, we investigate how the lifting eyes are designed and placed and why another set of eyes need to be added. Finally, we will explore other implications regarding the initial design change and the chances of providing ideas on how to navigate new challenges.

2.1 Caterpillar, Inc.

Caterpillar Incorporated, founded in 1925 in the state of California, is the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines, and diesel-electric locomotives through a worldwide dealer network (Caterpillar Inc.). Caterpillar, headquartered in the United States, is a company based on the trust between the organization and its customers (Caterpillar Inc). In addition to its US facilities, the company operates 110 manufacturing facilities worldwide, covering all of the inhabitable continents. Thus, "making progress possible and driving positive and sustainable change on every continent (Caterpillar Inc) ". These facilities are located in countries such as Australia, Belgium, China, Germany, France, and the United Kingdom, among others,

Caterpillar is also an industry-leading service provider. Their top services are Caterpillar Financial Services, Caterpillar Remanufacturing Services, Caterpillar Logistics Services, and Progress Rail Services (Caterpillar Inc.). These services are as integral to Caterpillar as the production of their world-renowned products.

Furthermore, Caterpillar Inc. has assured its leadership, presence, and importance within the industry. The company has been named on the Dow Jones Sustainability Index for 12 consecutive years. (Caterpillar Inc.) Caterpillar is a Fortune 500 company as well, demonstrating Caterpillar's overall success (Fortune 500). Part of its success comes from the customer service mentality. Caterpillar Group President Stu Levenick emphasizes that the goal of Caterpillar is to

guarantee to their customers that Caterpillar Inc is an organization they can build their future on, (Caterpillar Inc).

For last, by taking a closer look into Caterpillar's 2013 data it is shown in figure 1 that both sales and revenues during 2013 were down 16% due a sharp drop in sales of new mining machines; for a total of \$55.7 Billion. Additionally, in

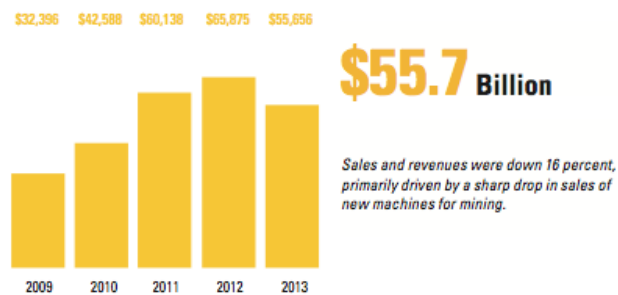


Figure 1 Consolidated Sales and Revenues (\$ in Million)
Obtained from Caterpillar's 2013 yearly report, page 51

figure 2 it can be determined that

approximately 36% of the sales and revenues came from the Energy & Power Systems with \$20,155 Million dollars. This is followed by the Construction Industries segment with \$18,445 Million dollars, representing approximately 33% of the sales and revenues.

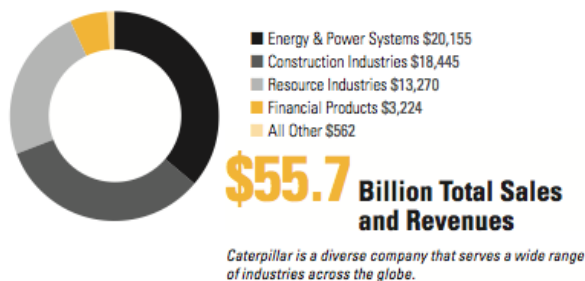


Figure 2 Consolidated Sales and Revenues by Segment (\$ in Million)
Obtained from Caterpillar's 2013 yearly report, page 51

It is important to mention that

Caterpillar's operations in Asia/Pacific and Latin America, which represent almost a third of the company sales, decreased in the first half of 2014 by 13% and 15% respectively. This reduction is directly related to a drop in the sales of the mining sector. On the other hand, the company grew 11% in North America due to

the sharp gains of the construction segment during the first half of 2014 (Cohen). In conclusion, it can be said that, although Caterpillar faced a tough year financially, but thanks to the great performance of the employees, Caterpillar obtained the strongest balance sheet they have had in 25 years. Thus, allowing the company to maintain (Caterpillar Inc) its position as industry and market leader worldwide (Caterpillar Inc.).

2.1.1 Major Businesses

In order to maintain its position as industry leader, Caterpillar has divided its operations into five different business segments. The creation of the divisions allows the company to provide better services while constantly improving. The mentioned business segments are as follows: Construction Industries, Energy and Power Systems, Resource Industries, Customer and Dealer Support, and Financial Products and Corporate Services. By dividing the company in segments, Caterpillar guarantees its presence in industries that support global growth and infrastructure development (Caterpillar Inc). Each division is explored more fully in the following sections.

Construction Industries

The Construction Industries segment is focused in building support for customers by providing the required machinery to build and develop a variety of infrastructure (Caterpillar Inc.). From highways to hospitals, this segment produces a machine that can help get the job done. The main responsibility of this segment is to support customers using Caterpillar machinery in infrastructure and building construction applications. This segment designs, manufactures and markets construction machines, including different types of wheel loaders, and, excavators (Caterpillar Inc.). Additionally, it provides customers with a business strategy, product design, product management and development, manufacturing, marketing and sales, and product support (Caterpillar Inc.).

The Construction Industries segment went through a difficult time during 2013, as seen from the figures below. First, we can observe in Figure 3 that sales went from \$19,334 to \$18,445 million dollars. Consequently, profit was reduced to \$1,363 in 2013, from \$1,789 million dollars in 2012.

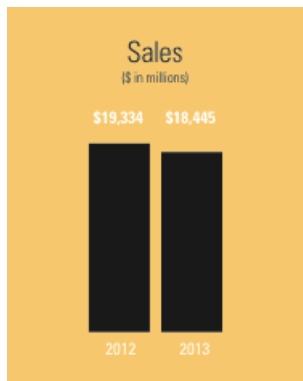


Figure 3: Constructions Industries Sales in 2012 & 2013

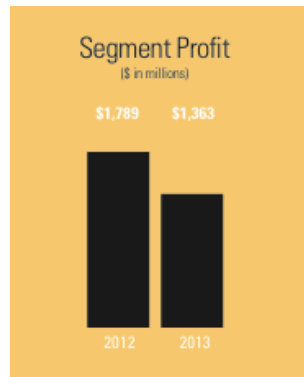


Figure 4: Construction Industries Profits in 2012 & 2013

Figure 5 shows the sales by region of the construction division during 2013. It is clear that the most sales were made in North America, worth \$7,008 million dollars, followed by the Asia-Pacific region, with sales amounting to \$4,690 million dollars (Caterpillar Inc.).



Figure 5: Construction Industries Geographical Sales 2013
Obtained from Caterpillar's 2013 yearly report, page 8

Energy and Power Systems

This division is dedicated to supporting implementation of different energy and power systems. Caterpillar created this segment due to the increase in energy and power demand. The manufacturing of “reciprocating engines, turbines and related parts across industries serving electric power, industrial, petroleum and marine applications as well as rail-related businesses” falls under this division of the company (Caterpillar Inc.).

The Figures below help to explain the performance of this segment in 2012 and 2013. Figure 6 demonstrates that sales decreased from \$21,122 to \$20,155 million dollars in 2013. In accordance with this trend, Figure 7 shows that profit in 2013 decreased to \$3,400 dollars. For last, figure 8 shows that the majority of the sales made in 2013 were made in North America, approximately \$8,231 million dollars (Caterpillar Inc.).

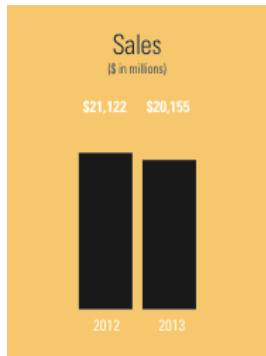


Figure 7: Energy & Power Systems Sales 2012 & 2013

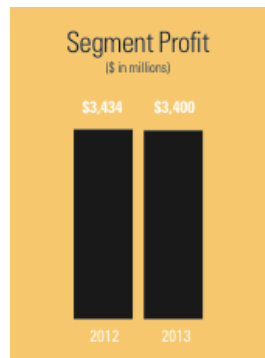


Figure 8: Energy & Power Systems Profit 2012 & 2013

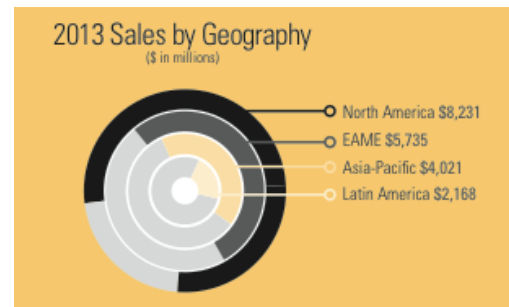


Figure 6: Energy & Power Systems Geographical Sales 2013

Obtained from Caterpillar's 2013 yearly report, page 21

Resource Industries

The main goal of the Resource Industries segment is to help the customer with the collection of valuable natural resources through mining, such as coal and iron. Its main department is Caterpillar Global Mining, which designs, manufactures, and markets surface mining equipment. The equipment includes “large track-type tractors, large mining trucks, and underground mining equipment” for different types of mining. Additionally, it offers paving, forestry, and tunneling equipment. The endless development opportunities for business solutions in this sector make it one of Caterpillar’s most promising departments. The Resource Industries division also manages integrated manufacturing and research-and-development, two departments which serve the entire company (Caterpillar Inc.).

The Resource Industry segment was one of the most affected by the decrease in business from 2012 to 2013. As seen in Figure 9, sales decreased by almost half of 2012 sales (\$13,270 million dollars). The profit of this segment was \$1,575 million dollars, less than half of the profit of 2012, which was \$4,318 million dollars (see Figure 10). The North American region accounted for nearly 33% of 2013 sales, the highest percentage of the regions as shown in Figure 11 (Caterpillar Inc.).

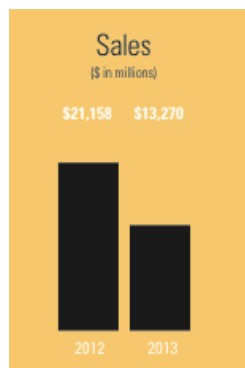


Figure 9: Resource Industries Sales 2012 & 2013

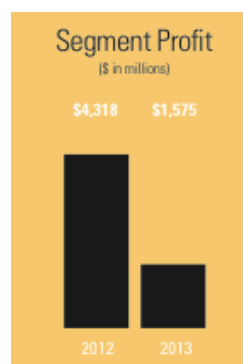


Figure 10: Resource Industries Profit 2012 & 2013

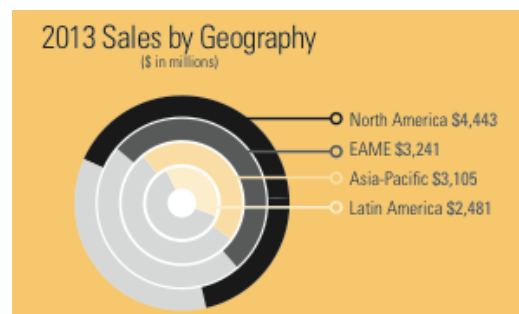


Figure 11: Resource Industries Geographical Sales 2012 & 2013

Obtained from Caterpillar’s 2013 yearly report, page 45

Customer and Dealer Support

The Customer and Dealer Support division plays a key role in the success of Caterpillar as an industry leader. This segment provides employee equipment training on job sites, supplying aftermarket parts and service support, and offering eBusiness and Equipment Management solutions to help Caterpillar's dealers provide their customers with the best quality service. As expressed by Caterpillar Group President Ed Rapp: "When it comes to quality, only the paranoid prevail (Caterpillar Inc)." In order to maintain its legendary quality standards, Caterpillar has implemented a zero defect mentality that has helped to reduce variation in production and guarantee an excellent customer experience (Caterpillar 2013 Year in Review: A Connected Caterpillar). Additionally, a key strength is the ability to provide remanufacturing solutions and provide dealers and customers with the best part availability at any time, delivered anywhere in the world. As a matter of fact, there are 178 Caterpillar dealers around the world. Since customers and their needs change as time goes by, Caterpillar has focused on improving its dealer network and service in order to satisfy those needs (Caterpillar Inc). Because of Caterpillar's customer service, quality and commitment with the industry, there are approximately 3 million CAT products in existence around the world (Caterpillar Inc.).

Financial Products & Corporate Services

In order to facilitate the purchase or lease of its products, Caterpillar created its Financial Products & Corporate Services segment to provide financing to customers, dealers, and suppliers. The company provides customized financing solutions through offices in more than 35 countries. Financing plans include operating and finance leases, installment sale contracts, working capital loans, and wholesale financing plans. The segment also provides "various forms of insurance to customers and dealers to help support the purchase and lease of equipment". Corporate Services is built to provide business and human resources, information technology, accounting and finance services to Caterpillar, serving as the enterprise resource for business-related activities" (Caterpillar Inc.).

The Financial and Corporate Services segment outperformed the rest of Caterpillar's divisions. Figure 12 demonstrates an increase in profits from \$763 million dollars in 2012 to \$990 million dollars in 2013, an increase of approximately 30%. Revenues also increased from \$3,090 million dollars in 2012, to \$3,224 million dollars in 2013 as seen in Figure 13. This

business segment mainly draws revenue from North America, where its revenue was \$1,688 in 2013, approximately 52% of the total revenues as shown in Figure 14 (Caterpillar Inc.).

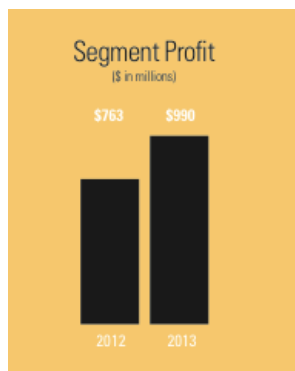


Figure 12: Financial & Corporate Services Profit 2012 & 2013

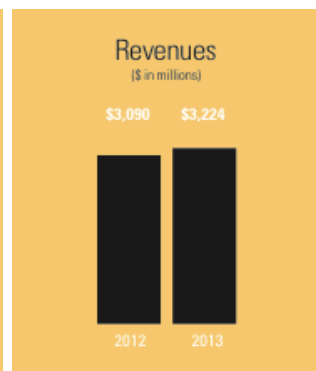


Figure 13: Financial & Corporate Services Revenues 2012 & 2013

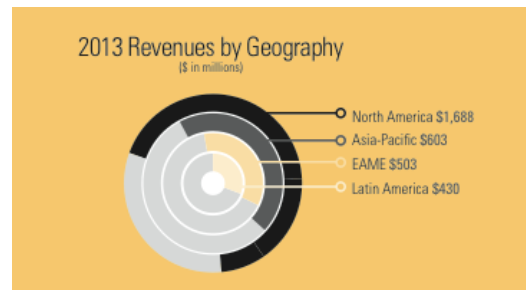


Figure 14: Financial & Corporate Services Geographical Revenues 2012 & 2013

Obtained from Caterpillar's 2013 yearly report, page 33

2.1.2 Caterpillar, Inc. in China

China, the leading manufacturer and exporter in the world, represents endless opportunities for companies in different areas and industries. Although, by 2013, the Chinese economy was slowing its growth, it would still represent a growth rate close to 8% (approximately USD 700bn), which exceeds the growth of any other large economy. (Willis Mining Market Review). Caterpillar Inc. began operations in China in 1975 and has continued expanding within the market since then through today. Throughout the years, Caterpillar has played a key role in the development of several Chinese industries. At the same time, it has played a positive role in saving energy and reducing emissions since the company has focused in implementing dual fuel engines that burn both natural gas and diesel fuel in more traditional machinery (Caterpillar).

Additionally, Caterpillar has 23 manufacturing facilities around China, 4 new facilities under construction, 3 logistics and parts centers, and 4 research and development centers. Currently, Caterpillar employs more than 15,000 people in China. The company has a network of more than 10,000 dealers and utilizes more than 16,000 suppliers that guarantee the company's legendary support and quality of service (Caterpillar Inc.).

When Caterpillar starts operations in a new market abroad, they specifically hire local

managers. This policy works to integrate the local culture with the company culture to ensure the moral of workers. Therefore, when Caterpillar started its operations in China in 1975, it was a priority for the company to hire and train leaders that could be capable of taking care of the local operations (Caterpillar Inc)

During this project, the team will work directly with the Caterpillar (Suzhou) Co. Ltd. The main focus of this facility is to produce world-class medium wheel loaders and motor graders for markets in South America, Middle East, Asia Pacific, Russia, and Africa. Specifically, the project will focus on the 980H2 Steel Mill Application Wheel Loader; the design of which is explored in the following section.

2.2 The 980H Wheel Loader

In this section, more specific information is provided on the 980H Wheel Loader to more fully understand the machine. In order to comprehend the machine's structure, it is important to clarify the sides of the machine. Therefore, as seen in figure 15, the design side will be defined based to the 980H2 machine operator point of view. There will be the right side battery box and the left side battery box. The right side will be the one to the right of the operator, and the left side one will be at the left side of the operator. The right side has a battery box and toolbox, while the left side has only the battery box since the tilt group was removed due to the engine hood change.

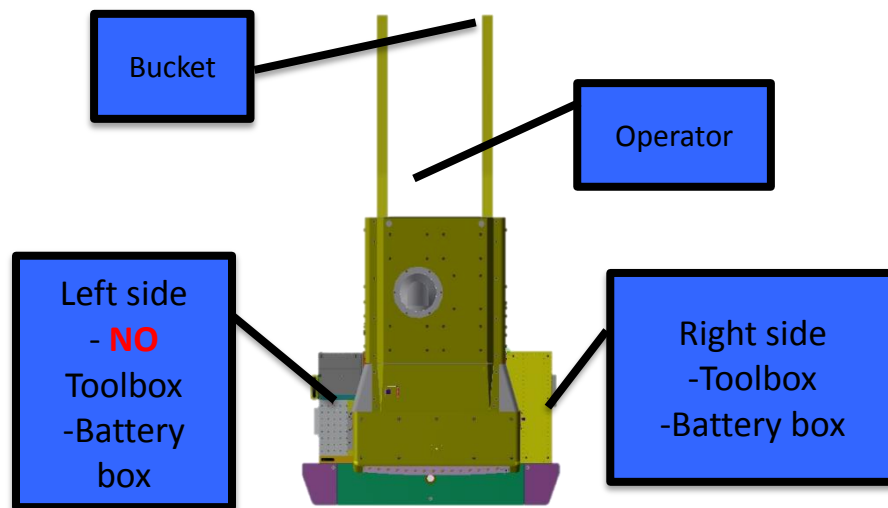


Figure 15: 980H2 Series Machine Top View

Wheel loaders are extremely popular for use in construction and mining. The 980H2, with an operating weight of 30,519 Kg (67,294 lb.), a height of 3.7 meters (12'4"), and a length of more than 6 meters, is one of the favorites of Caterpillar's machinery products. This model's prominence in the industry comes from its ability to provide an excellent cargo capacity, and its versatility. As a matter of fact, Caterpillar offers an extensive variety of buckets, work tools, and couplers, in order to customize the 980H. There are several special application models of the 980H Wheel Loader; these models are engineered for specific purposes, such as withstanding high temperatures or lifting material higher than other applications require. The following is a list of the different buckets and applications of the machine to show the adaptability of the machine:

- Buckets: General Purpose, Material Handling, Rock Buckets, Waste, Coal, Heavy Duty Quarry and, Woodchip and Clean Up.
- Applications: Aggregate, Forestry, Industrial, Steel Mill, and High Lift Arrangements (Caterpillar Inc.). (Dong, Visit to Caterpillar Suzhou Facility)

The 980H Wheel Loader is built to last, as are all Caterpillar products. The 980H model has a solid structure; its main components are designed and manufactured to provide long hours of use. Additionally, the engine of the machine is the Cat C15. This model is designed to maintain its performance, efficiency, and durability, while reducing emissions. According to Caterpillar's machine specifications, this model has special shocks to keep all components aligned correctly to prevent malfunction of any parts when the machine rides over rough terrain. Furthermore, "the frame is over 90 percent robotically welded providing deep-weld penetration for maximum durability and fatigue strength." (Caterpillar Inc.) The 980H Wheel Loader is designed to lift heavy loads. Therefore the frame must be designed to withstand the forces associated with the arm and bucket of the machine.

While durability is an important factor to Caterpillar and their customers, safety is also a top priority (Dong, Visit to Caterpillar Suzhou Facility). Thus, Caterpillar has designed the 980H with the safety of the operators in mind. The operator uses a ladder to enter and exit the cab; this is dangerous, since a fall from the cab can cause severe injuries. In order to address this concern, Caterpillar implemented a ladder with self-cleaning steps (Caterpillar Inc.). The ladder

is also at a 5-degree incline for easier entry and exit. The platforms on the sides of the machine are wide, allowing for more secure movement along the machine. These measures make this machine one of the most secure, efficient, and reliable in the industry

This project will be based on a variation of the 980H, the 980H2 Steel Mill Wheel Loader. This design variation is achieved due to the versatility of the 980H, as explained previously. This special application provides extra protection, which is needed in order to extend the life and lower the operation cost of the machine in its rough environment. The Steel Mill application machine has to withstand working temperatures as high as 1200 degrees centigrade, which calls for several design changes to ensure the safety of the operator and protection of machine components. As mentioned in Caterpillar's 980H catalog, the arrangement includes: "steel guarding for critical components, an extreme service transmission, heavy-duty engine and transmission mounts, hydraulic hose protection, insulated battery mounting, remote engine shutdown, remote parking brake release, transmission override, steel cable ladder, steel command control steering shaft cover, seal mounted windshield for quick replacement, and narrow steel front fenders." All of these special upgrades guarantee that the machine will perform at its finest during its heavy duty application, demonstrating Caterpillar's product quality. The new version of the Steel Mill application also includes a steel hood (Caterpillar Inc.).

2.3 The Battery Box

There are two battery boxes on the 980H Wheel Loader. There is one on each side of the machine underneath the engine. In order to refer to the sides of the machine, we will determine them from the operator's point of view: facing the bucket of the machine, with the battery boxes behind the operator. Currently, the battery box on the left side is responsible for holding the battery and the hood tilt group. Additionally, it has an anti-slip tread step cover so that the box also functions as part of a step to reach the cab. The existing 980H Wheel Loader model has a fiberglass hood. A steel hood per customers' requests will replace the fiberglass hood. This change, shown in Figure 16, is the main problem of the project. (Worcester Polytechnic Institute)

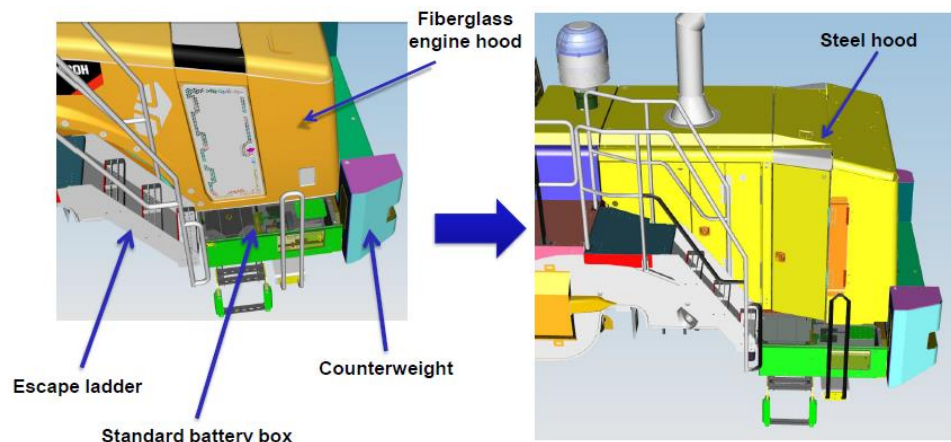


Figure 16: Comparison of Fiberglass and Steel Hoods on the 980H Wheel Loader

Obtained from WPI & Caterpillar Project Description

As previously explained, the battery box holds the battery and the tilt group (left side). The tilt group automatically opens the fiberglass hood using hydraulic systems. However, this tilt group will no longer exist as the steel hood is too heavy to open automatically. Additionally, the Steel Mill application requires that any maintenance work be done off-site and out of dangerously high temperatures, so there is no need to open the hood for quick maintenance. Therefore, the battery box must be redesigned to remove the tilt group and solve any interference with the new steel hood design.

The battery box is made of several components. As previously mentioned, there are two batteries on this model, one on either side of the machine. They are placed in the same approximate location, but each has its own parts to fit the correct side. Figure 17 shows the design and the placement of these components for both battery boxes.

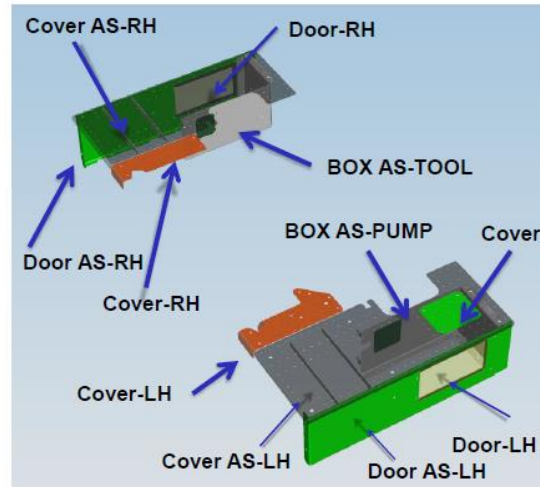


Figure 17: Battery Box Design with Components
Obtained from WPI & Caterpillar Project Description

Each component is priced differently. This is caused by the difference in design and manufacturing of each part. Table 1 outlines all of the components of the box and their respective prices. It is important to mention that the prices are shown originally in Chinese Renminbi or Yuan (CNY) and the team converted them to US Dollars (USD). The exchange rate USD to CNY on July 7th, 2014 was \$1 to ¥6.2.

Object Description	QUANTITY	COMP UNIT	PRICE	PRICE
BOX AS-TOOL	1	PC	¥163.25	\$26.33
COVER	1	PC	¥30.41	\$4.90
COVER AS-RH	1	PC	¥264.00	\$42.58
BOX AS-OUMP	1	PC	¥158.65	\$25.59
COVER-RH	1	PC	¥57.51	\$9.28
COVER-LH	1	PC	¥72.69	\$11.72
DOOR AS-LH	1	PC	¥214.24	\$34.55
DOOR AS-RH	1	PC	¥202.15	\$32.60
DOOR-RH	1	PC	¥45.90	\$7.40
DOOR-LH	1	PC	¥45.90	\$7.40
		TOTAL	¥1,517.06	\$244.69

Table 1 Battery Box Components and Prices
Obtained from WPI & Caterpillar Project Description

2.4 The Lifting Eyes

The 980H2 Wheel Loader is a massive machine. Occasionally, the customer might need to use the machine in a specific area of the site that is inaccessible by driving the machine. Therefore, Caterpillar located two sets of lifting eyes on the frame of the machine. These lifting eyes are placed on the frame and have holes so that a hook can be used to lift the machine. Figure 18 shows a wheel loader being lifted to a different area on the site using the lifting eyes.

In order to lift the machine, the lifting eyes are located on the main frame of the Wheel Loader, the strongest part of the body. On the 980H, one set of lifting eyes is reachable only by opening the hood (figure 19). Since the hood was made of fiberglass, and it opened automatically, the lifting eyes were easily accessible. However, to open the new hood design, the entire steel hood must be removed as one assembly. Thus, once we have finished the redesign of the right and left side battery box, we will focus in providing suggestions for the relocations of the lifting eyes that are more easily accessible.



Figure 18: 980H being lifted

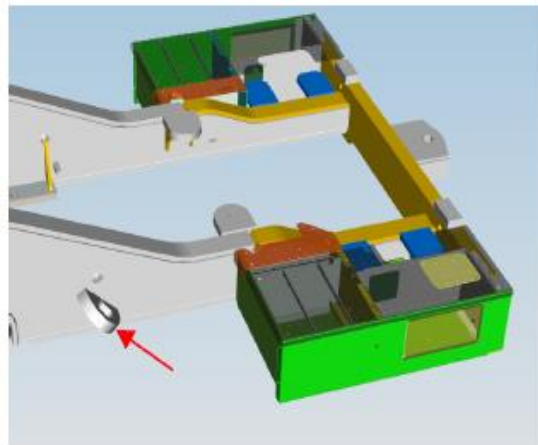


Figure 19: Location of Lifting Eyes in 980H

Obtained from WPI & Caterpillar Project Description

2.5 Summary

In the background chapter, we have conducted research on Caterpillar Inc.: what makes the company an industry leader, how it operates, and the different divisions within the company. Additionally, we took a closer look into the 980H Wheel Loader and the 980H2 Steel Mill Wheel Loader. In doing so, we explored the current design of the battery box on both sides of the machine. We have identified the motivation for the redesign of the battery box and relocation of the lifting eyes on the 980H2 Steel Mill Application Wheel Loader. In the next chapter, we will identify the methods through which we will tackle our project goal: to redesign the battery box by solving interferences and reducing cost.

Chapter 3: Methodology

The goal of this project is to redesign 980H2 Steel Mill Battery Box for Caterpillar Incorporated to solve the interference and reduce cost. To achieve this goal, the team developed the following objectives:

1. Generate a list of design specifications for the battery box from our Caterpillar contact
2. Create an evaluation system of criteria based on what is most important to Caterpillar and their customers
3. Show the opportunities for using less material and thus reducing cost
4. Evaluate design options based on the criteria generated in Objective 2
5. Provide a few ideas for the relocation of the lifting eyes that will work with the new design of the machine

This chapter will outline the methods that we will use to complete the above objectives.

3.1 Objective 1: Design Specifications

To create a new design, we first generated a list of design specifications based on the needs of Caterpillar, Inc. During our preparation in D term, we started to build a list of requirements from our mentor. After our meeting with our mentor and seeing the machine in person, we developed a completed list of design requirements. In addition, we asked our mentor to both rank and weight each requirement, which helped us to analyze the designs that the team created. Below is the list of design specifications:

1. Reduce Cost
2. Material stays the same
3. Do not change battery box
4. Toolbox (Right Side) Specifications
 - a. Maintain customer functionality
 - b. Door area remains the same
5. Left Side Specifications
 - a. Minimal changes to keep manufacturing cost low
 - b. Changes to stairs and handrails must comply with ISO2867

3.2 Objective 2: Evaluation System

First, we discerned the most important factors to Caterpillar and their customers from our initial meeting with our sponsors in Suzhou, China. We found that the two criteria most important to Caterpillar are reducing cost and meeting customer needs. When the team looked more closely at these criteria, we found a few areas to focus on and metrics with which to measure our progress.

First, in cost reduction we focused on the manufacturing cost. While we cannot know precisely how much a new design would cost to redesign, from the background knowledge of the Industrial Engineers in our team, we can make assumptions as to what would be more costly to produce. The metric we decided to use was the percentage of the mass of material reduced. In addition, we emphasized simplicity and relation to the old design so as to reduce the cost of manufacturing.

Second, to meet all of the customer needs, we found that there were several additional standards the design should meet. The toolbox must be functional, meaning that there should be no way for the tools to fall out and no interference between the door and other parts of the machine. The customer is also concerned with safety, thus any changes to the stairs that lead to the cab must comply with the standards set out in ISO2867 and should make climbing to the cab easy.

After looking at these criteria, the team came up with our own criteria that we wanted to meet to try to create the best design possible. Space optimization is important to us so that we give Caterpillar and their customers a machine that takes the smallest spaces, but makes valuable use out of it. To measure this we will look at the usable space in the old design and compare it with the area of usable space in our designs. Subsequently, we decided that innovation was important to the design. However, measuring innovation is mainly subjective, thus this metric will be determined by how innovative the team feels the final design is. The last measure that the team came up with was quality. We felt that quality is one of Caterpillar's main selling points for their products from looking at their website. The metric we decided that this would be whether or not we met the ISO standards and whether we exceeded expectations in terms of the other requirements.

From these performance metrics, we found that we also needed a more concrete evaluation system to incorporate the importance of each criterion and also the relationship between them. The team conducted research and used knowledge of past Industrial Engineering principles to find different evaluation techniques. We considered a simple weighted grading system, where Caterpillar would provide a percentage out of 100 for each criteria, which would then be multiplied by the score for each criterion. However, the team decided that this did not adequately represent the relationships between customer needs and other important aspects of the design. In our research, we found the House of Quality to be an evaluation system which represents the weights of each design aspect and customer needs and the relationship between the design constraints and metrics. Thus, we chose the House of Quality as our evaluation system. We explain how the House of Quality system works in extreme detail in Chapter 5: Evaluation.

3.3 Objective 3: Cost Reduction Opportunities

While providing the functions needed by customers was most important to Caterpillar, there was an additional need to reduce the cost of these parts. Our team decided that one of the easiest ways to reduce cost would be to reduce the amount of material used in the components. Thus, we based our designs on using the least amount of material possible. To demonstrate the cost reduction opportunities, we used the percentage of mass reduced between the designs. As Caterpillar is charged per kilogram of material, this would be the easiest for our sponsors to understand the exact dollar amount we had reduced in cost.

In addition, we had to think of the manufacturing of these components. Ease of manufacturing can significantly cut down on the cost of the components. Thus, we tried to also create the simplest components possible to help reduce cost.

3.4 Objective 4: Evaluate Designs

In our design process, we brainstormed a multitude of concept designs. From these concept designs, we created computer models of the concept designs that best fit the design requirements. We analyzed these select designs, and graded them on how well they met the design specifications and criteria. To grade the designs, we used the House of Quality method

explained in Objective 2. This method incorporates which criteria are most important to our sponsor. After we evaluated our models using the House of Quality, we decided on the best design to present to Caterpillar, Inc. in the final presentation. When we presented this design, we demonstrated why we chose this as the top design over the others.

3.5 Objective 5: Lifting Eyes

In addition to creating the design of the battery box, we also produced several concept designs for the relocation of the lifting eyes. To do this, we investigated the computer models of the machine. Given that the scope of our project is defined as providing a few ideas rather than a concrete design, we investigated our concept designs using the simulation software. After investigating the concept designs, we chose the 2 ideas we felt were the best option for our sponsors.

3.6 Schedule and Task List

1. Finalize Design Requirements (Week 1) (list out the design requirements that we have right now)
 - a. Check design requirements with our mentors
 - b. Have the mentors rank/weight the list so that we know what requirements are most important
2. Understand the problem (Week 1)
 - a. Ensure the whole team is on the same page
 - b. Re-work problem statement, goal, and objectives
3. Brainstorm ideas
 - a. Toolbox design
 - b. Design for the side without a toolbox
4. Make the criteria to compare our designs
5. Compare and choose the best 2-3 concept designs
6. Design & Redesign
 - a. Design the 2-3 concept designs in Pro/Engineer
 - b. Redesign – when the designer finds conflicts between the real design and actual design:
 - i. Brings problem to the whole group
 - ii. Brainstorm ways to get around the issue
 - iii. Try to design with the new concept design
 - c. When they are done, send models to mentor to make sure we have created a good design, if not redesign
 - d. If we have 2 designs at the end, apply the criteria and choose the best one
7. Cost Analysis
8. Brainstorm ideas for the lifting eyes
9. Finish Paper
 - a. Ensure that all the requirements are met for WPI
 - b. Have Professor Rong read it over and give feedback
10. Finalize Presentation
 - a. Create presentation

Task	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Update problem statement, objectives and objectives	X						
Become familiar with the design and software	X						
Get more information from Caterpillar Contact	X	X	X	X			
Establish criteria and evaluation system			X	X	X		
Establish design strategy (Divide designing process in steps)		X					
Establish right side design strategy		X					
Start right side design		X	X				
<i>Solve Red Piece interference</i>		X					
<i>Design toolbox door</i>			X	X			
Establish left side design strategy				X			
<i>Start left side design</i>				X	X		
Redesign (if needed)					X	X	
Visit Caterpillar to have final OK regarding models				X			
Evaluate designs and chose one					X	X	
Brainstorm ideas for lifting eyes location					X	X	
Finalize paper and presentation						X	X

Table 2 Project Task List by Week

We completed the above task list in the defined 7-week period while on site at the Huazhong University of Science and Technology. The team will in no way share any of Caterpillar's trade secrets, and only uses pictures of the models for the purpose of demonstrating the work we have done. All models were stored on a password-protected computer during the design process and we had access only to a portion of the model for our design purposes.

Chapter 4: Design

In this chapter, we will explain the design process the team followed throughout the project and the final designs that the team created. The team split up the design into parts because of the differences in specifications, as mentioned in Chapter 2. Figure 20 shows these differences: the right side has a battery box and toolbox, while the left side has only the battery box. The team split the designs into the following sections: the right side, the left side, and the lifting eyes. This chapter is organized into the same design segments.

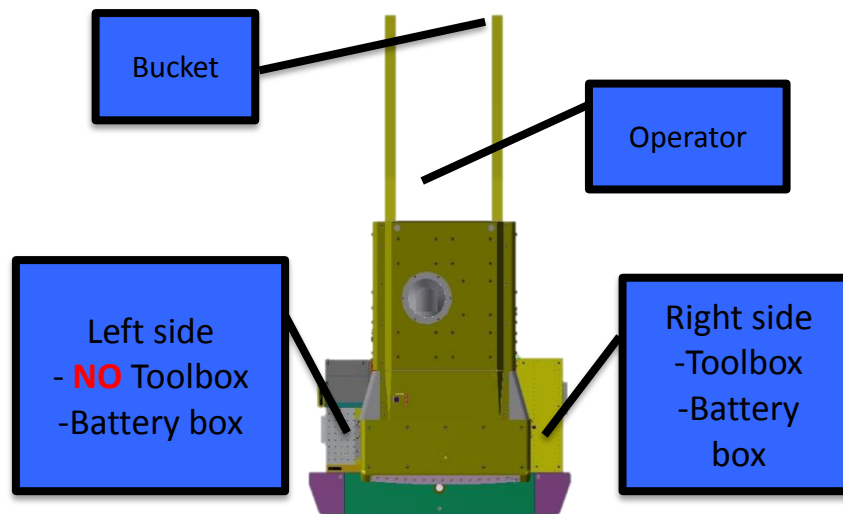


Figure 20: 980H2 Description of Sides

Part 1: Right Side Designs

The task on the right side of the machine was to solve any interference with the battery box/toolbox. For this, we further split the designs on this side between the interference within the toolbox, handrail interference, and toolbox door interference. As the toolbox only exists on this side of the machine, designing a functional and interference-free toolbox was the focus of the designs on this side.

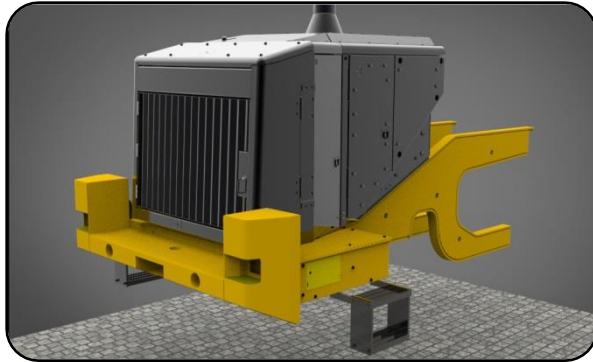


Figure 21: Right Side of the 980H2 Model

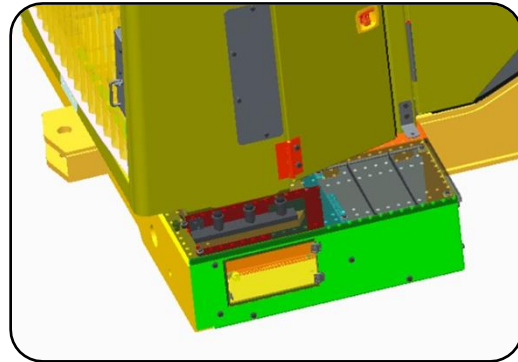


Figure 22: Toolbox and Battery Box

The toolbox is a rectangular shape as seen in figure 21. Its internal structure consists of a red piece that covers the back and left side of the toolbox and a yellow piece that helps to support the hood. The purpose of the mentioned red piece is to cover and protect cables that were originally part of the tilt group. However, there exists interference within the toolbox pieces, which is shown in Figure 22 and also in more detail in Figure 23 (below). In order to proceed and achieve our goal, the team divided the design process on the right side into three steps. First the interference within the toolbox was solved. Once several feasible solutions were created, the team proceeded to solve the interference between the toolbox door and the handrail.

1.1 Toolbox Interference Solutions

In order to have a better understanding of the internal interference, a detailed view of it is provided in Figure 4. Originally the toolbox volume, as shown in Table 3 was 41,684 cm³. The team came up with several ideas for solving this interference. We chose the following three ideas to redesign the red piece of the toolbox, and these designs are explained below.

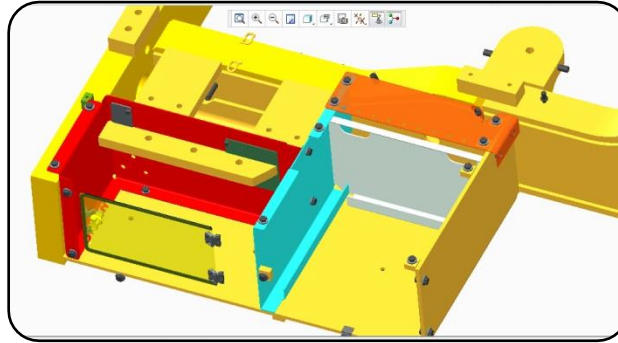


Figure 23: View of Internal Toolbox Parts

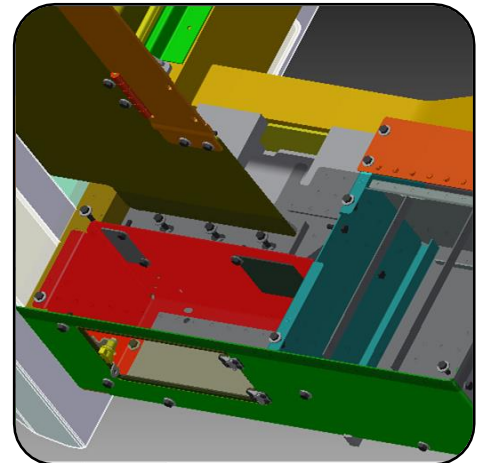
	Height	Width	Length	Volume
Original toolbox	28.29 cm	29.15 cm	51.50 cm	42,466 cm ³
Interference piece	2.90 cm	6.20 cm	41.49 cm	781.5 cm ³
Toolbox with the Interference				41,684 cm ³

Table 3: Original Toolbox Volume Calculations

Red Piece Solution #1

For the first solution, as seen in Figure 24, the red piece was moved forward in order to avoid any interference with the yellow piece. The width of the toolbox was determined to be 24.4 cm instead of 29.15 cm (Table 4). Additionally, it is important to mention that originally, the volume of the toolbox was 669,776.904 mm³, but after moving the red piece forward the volume was reduced by 14%, as shown in Table 4.

Figure 24: Red Piece Solution #1



	Height	Width	Length	Volume
Rectangular dimensions	28.29 cm	24.40 cm	52.3 cm	36,114 cm ³

Table 4: Red Piece Solution #1 Dimensions

Red Piece Solution #2

For this solution, the team combined the red and yellow pieces into a single piece. This arrangement means that the yellow piece would curve and meet the bottom of the box at a 45° angle. By combining both pieces, as seen in Figure 25, the volume of the toolbox was reduced by 7.5%. Additionally, as seen in Table 5, the dimensions of this solution can be seen. However after getting feedback from our Caterpillar contact, the team realized that this solution is not feasible since an external piece cannot be combined with the main frame of the machine.

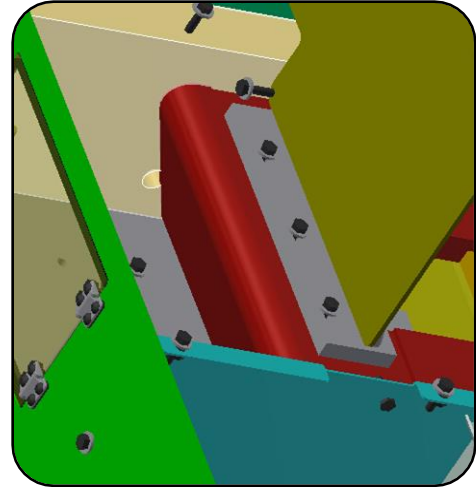


Figure 25: Red Piece Solution #2

Section	Height	Width	Length	Volume
Triangular	16.96 cm	5.768 cm	52.3 cm	2,468 cm ³
Rectangular	28.29 cm	24.40 cm	52.3 cm	36,114 cm ³
Total volume				38,582 cm ³

Table 5: Red Piece Solution #2 Dimensions and Volume Calculation

Red Piece Solution #3

In this solution, the red piece is shown as a pink piece due to software configurations. This design consists of attaching the red piece below the yellow piece, just before the brackets that support the yellow the piece (Figure 26). Additionally, the dimensions of this solution are shown in Table 6

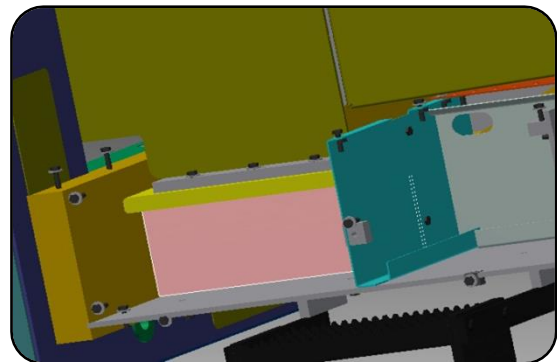


Figure 26: Red Piece Solution #3

Section	Height	Width	Length	Volume
Small Rectangle	16.96 cm	6.55 cm	52.3 cm	5,810 cm ³
Large Rectangle	28.29 cm	24.40 cm	52.3 cm	36,114 cm ³
Total volume				41,924 cm ³

Table 6: Red Piece Solution #3 Dimensions and Volume Calculation

1.2 Handrail Interference Solutions

Originally, as seen in Figure 27, the team believed that there was interference between the handrail and the toolbox door. Therefore, four solutions were designed in order to solve the mentioned interference. Finally, after receiving feedback from our Caterpillar contact, the team learned that there was no handrail on the right side of the machine.

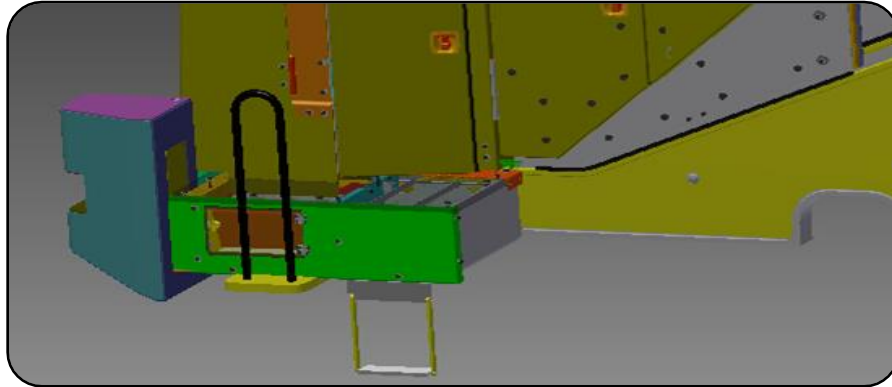


Figure 27 Original Handrail View

As a result, the four designs were unnecessary to the final suggestions to Caterpillar. Regardless of the previous finding, the team felt that they are important to show in our design process. Thus, the four designs are explained in this section.

Handrail Solution #1

Solution #1 (Figure 28), consists of moving the handrail all the way to the right of the battery box, just before the wheel. This caused a slight shift in the placement of the steps towards the toolbox. Additionally, the orientation of the handrail was changed in order to provide more comfort and safety to the operator or technician when climbing the structure.

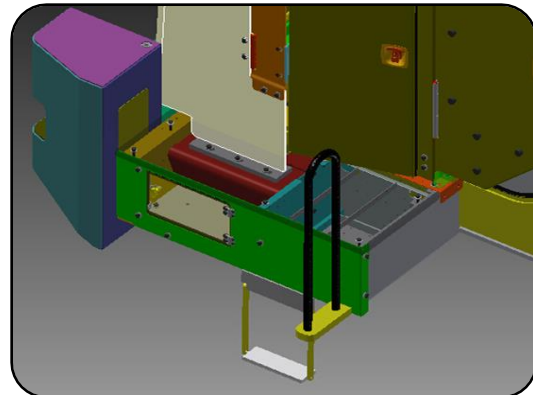


Figure 28: Handrail Solution #1

Handrail Solution #2

As seen in Figure 29, Solution #2 consists of attaching the handrail above the toolbox door. The rail would be attached to the top of the green piece of the toolbox instead of the bottom. In this design the orientation of the handrail was not changed.

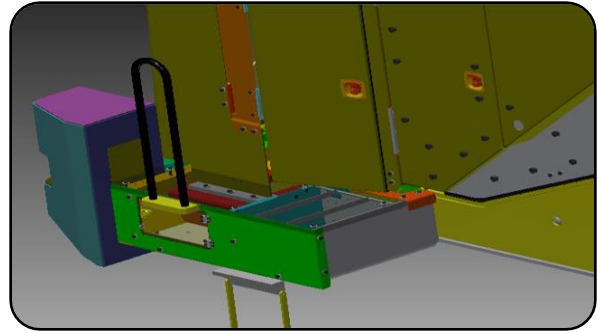


Figure 29: Handrail Solution #2

Handrail Solution #3

In this solution, the handrail is attached to the door of the toolbox. Additionally, the orientation of the handrail was not changed, as seen in Figure 30. Finally, the only concern regarding this design was that the handrail and door combination would have to be strong enough to support the weight of the operator.

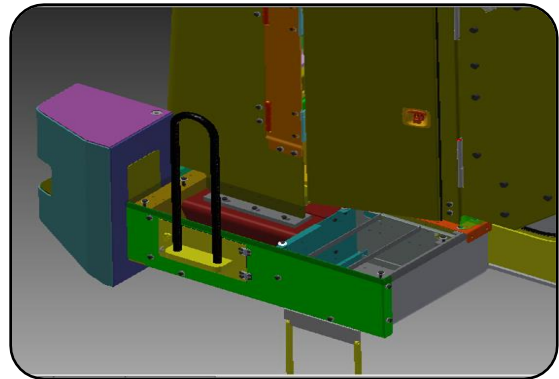


Figure 30: Handrail Solution #3

Handrail Solution #4

Solution #4 (Figure 31) is an extremely simple approach to solving the interference. The orientation of the handrail was changed, but its location remained the same as the original design.

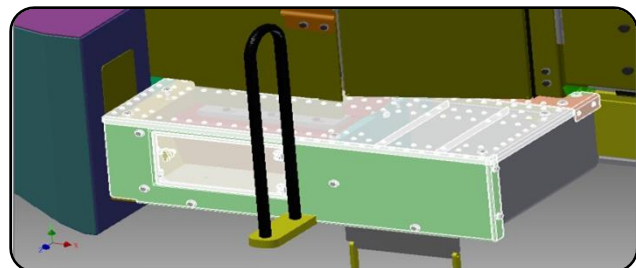


Figure 31: Handrail Solution #4

1.3 Toolbox Door Interference Solutions

Once the red piece interference was solved, the team focused in improving the toolbox door in order to find cost reduction opportunities. However, after receiving feedback from our Caterpillar contact, the team learned that the toolbox door could not be changed. The team could only relocate the door from the side of the toolbox to on top of it. We had to consider that Caterpillar only produces about 10 of these Steel Mill application machines a year (Dong, Visit to Caterpillar Suzhou Facility), so making any drastic changes would prove to be more costly in manufacturing, regardless of the material saved by changing the door. Below, we explain our concept designs for changing the toolbox door.

Toolbox Door Solution #1

This concept design consists of using the top of the toolbox as the door. By doing so, the door will open towards the hood. This idea would allow the operator have better access to the tools. In order to do this, as shown in Figure 32, the top part of the toolbox and battery box will become two separate pieces instead of a single one.

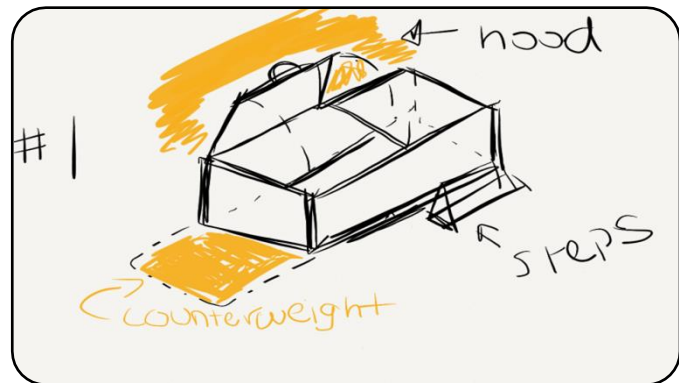


Figure 33: Toolbox Door Solution #1

By doing this the operator will have better access to the tools, and more usable volume.

Toolbox Door Solution #2

This solution is similar to Solution #1, but instead the door opens towards the counterweight at the back of the machine (Figure 33). In order to do this, the top part of

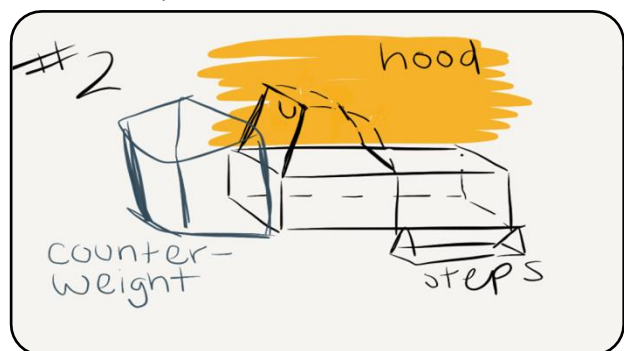


Figure 32: Toolbox Door Solution #2

the toolbox and battery box will become two separate pieces instead of a single one.

Therefore, the operator will have better access to the tools, and can use more of the volume of the box. Finally, we will add a handle to the door to either its side or the top part in order to allow the operator open the door.

Toolbox Door Solution #3

Solution #3 consists of moving the original door from the side to the top part of the toolbox (Fig. 34). This idea is similar to the previous two solutions, but the main difference is that the size of the door will be similar to the original one. Additionally, the door will open towards the counterweight, allowing the operator have a better access to the inside of the toolbox.



Figure 34: Toolbox Door Solution #3

Toolbox Door Solution #4

Solution #4, as seen in Figure 35, consists of creating a trapezoidal toolbox. The door will open towards the hood and be at a 45 degree angle. Additionally, a handle will be added in order to facilitate the opening and closing process. In order to do this, the top part of the toolbox and battery box will become two separate pieces instead of a single one. By doing this the operator will be able of having a better access to its tools, and even putting more of them into the toolbox. In addition, the front piece would have to be changed or split into two sides



Figure 35: Toolbox Door Solution #4

Part 2: The Left Side

Once the right side designs were completed, the team focused in improving the left side of the machine (Figure 36) in order to identify cost reduction opportunities.

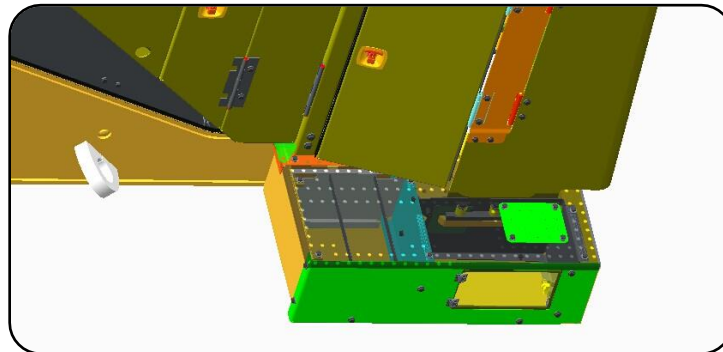
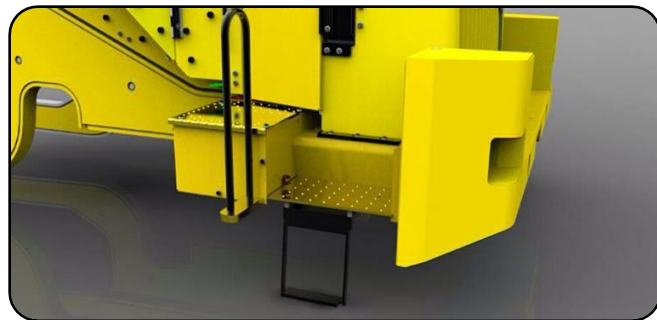


Figure 36: Left Side Original Design

Since the left side does not have a toolbox, due to the tilt group. On this side, the team has a greater level of freedom for creating solutions. One reason for this is the removal of the tilt group, which leaves space to reduce more material. It is important to mention that Caterpillar only manufactures 10 of these machines a year (Dong, Visit to Caterpillar Suzhou Facility); therefore, they want to see small changes in the structure that are cost effective and easy to implement. As a result, the team designed 4 solutions that will be explained below:

Left Side Solution #1

In Solution #1 (Figure 37), it can be observed that both the top and front part of the empty box were removed. Additionally, the stairs were relocated from the bottom of the battery box to



the empty space, and the orientation of the handrail was changed as well. By removing the top and front part, we removed 0.307184 m² or 30.7184 cm² of material, which represents 67% material reduction.

However, after receiving feedback from our Caterpillar contact, the team learned that the design is not feasible since the solution did not meet the ISO 2867 standards for handrails and stairs.

Left Side Solution #2

Solution #2 (Figure 38) is similar to Solution #1. There is a difference in the addition of a small handle on the right side of the steps in order to allow the operator to easily climb up the stairs. Finally, the orientation of the handrail was not changed. It is important to mention that after receiving feedback, the team learned that the design was feasible, but minor changes were required to make sure that the design met the ISO 2867 standards.

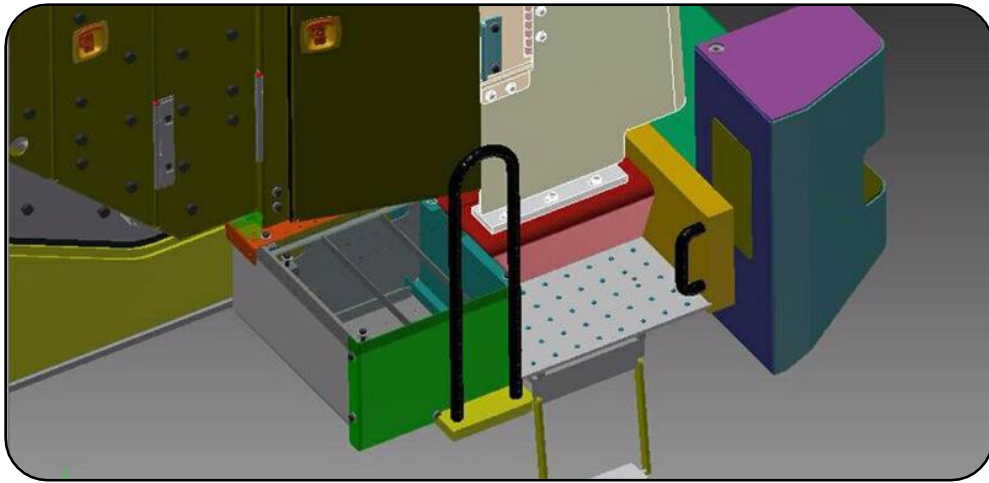


Figure 38: Left Side Solution #2

The redesign of Solution #2 is shown in Figure 39. The differences between the original solution and the redesign are the right handrail and the steps. These were changed to meet the ISO 2867 standards. Originally the design had 4,290,378.70 mm³ of material. After the redesign, it had 2,255,374.16 mm³, saving 2,035,004.54mm³ of material. This represents 47.43% of material reduction.



Figure 39: Left Side Solution #2 Redesign

Left Side Solution #3

Solution #3, as seen in Figure 40, consisted of removing all of the tilt group area. Afterwards, a ladder was attached to the main frame in order to guarantee stability. Also, this solution met the ISO 2864 standard. Approximately 43.82% of material was reduced in this solution. This amount of material is a rough estimate since we did not have access to the entire stair assembly per Caterpillar policy. However, we expect that this number will be larger since we can remove parts of the handrail.

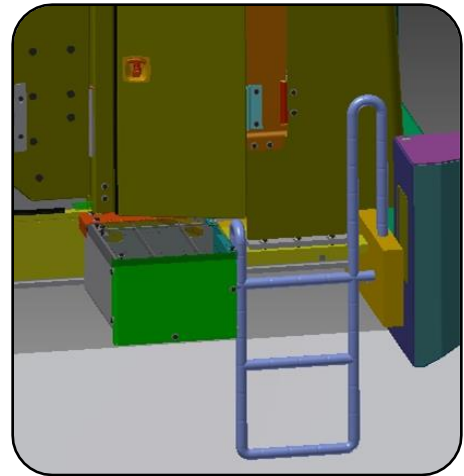


Figure 40: Left Side Solution #3

Left Side Solution #4

Solution #4, as seen in Figure 41, consisted of removing the entire toolbox and relocating the handrail to the right side of the battery box. It is important to mention that this design meets the ISO 2864 standard. The original amount of material in the design was 9,549,278.22 mm³. However, the design of the solution had 5,364,449.61 mm³, representing a savings of 4,184,828.61mm³ of material. This can be translated to 42.78% material reduction.

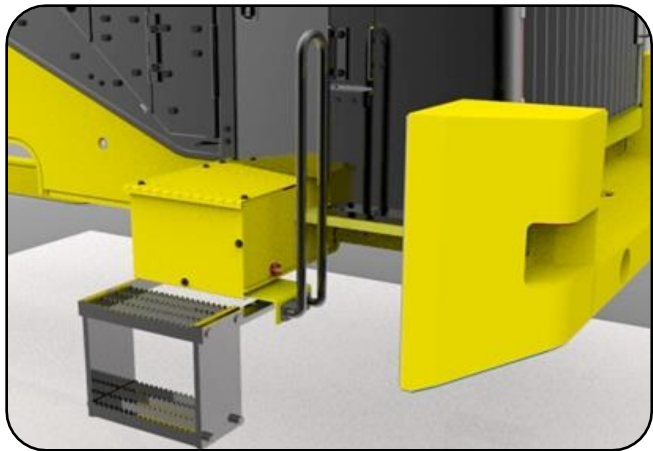


Figure 41: Left Side Solution #4

Part 3: The Lifting Eyes

In the original design, the lifting eyes were located inside the engine hood. In order to use them the hood had to be opened via the tilt group. Since the hood material changed, and the hood must be removed as a full assembly, the lifting eyes are not easily accessible. Therefore, the lifting eyes must be relocated. The constraints for the lifting eyes are that they must be relocated on the frame and farther to the rear of the machine than the previous lifting eyes for stability. It is important to mention that these are not the focus of our project, and more time and emphasis was placed on the battery box redesign. Below, we explain our suggestions for relocating the lifting eyes.

Lifting Eyes Suggestion #1

The first suggestion for the relocation of the lifting eyes is to attach them to the main frame right before the counterweight. On the left side, Figure 43, it can be observed that there is enough space to operate in a comfortable way.

In Figure 42, it can be observed that, on the right side, the relocation is more complicated. Since the right side has a toolbox, the lifting eye would have to be inside the toolbox to match the other side. Additionally, the toolbox door would have to be relocated in order to allow its use.

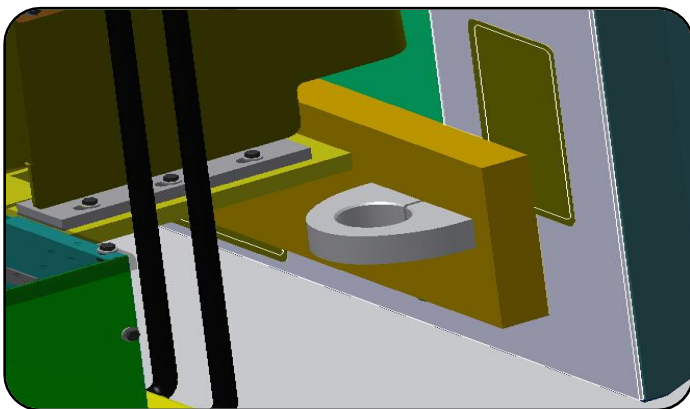


Figure 43: Lifting Eyes Suggestion #1: Left Side

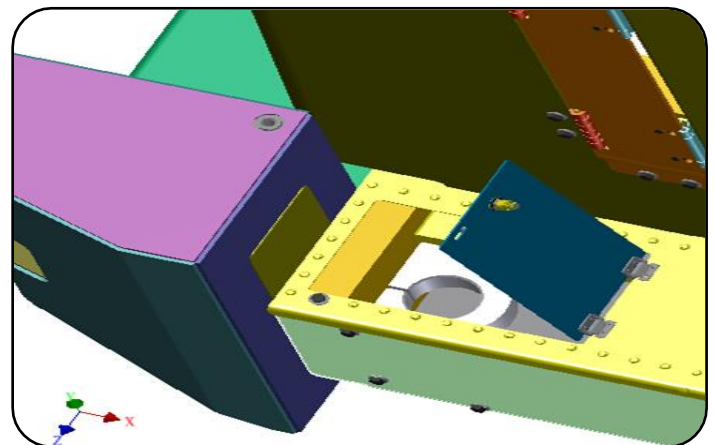


Figure 42: Lifting Eyes Suggestion #1 Right Side

Lifting Eyes Suggestion #2

Solution #2 consisted of attaching the lifting eyes to the top of the main frame (yellow piece) with an angle. As seen in Figure 44, the right side one would need a special cut in the top of the battery box in order work properly. On the other side, Figure 45 shows the lifting eye on the left, and since there is no toolbox, it is easier to access and utilize.

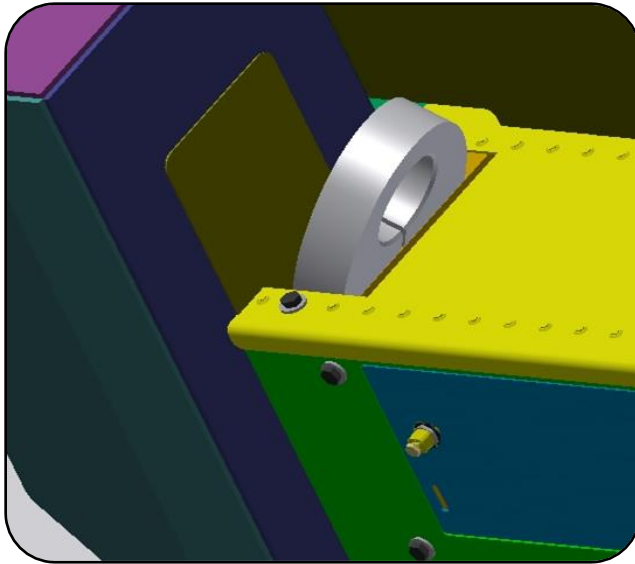


Figure 44: Lifting Eyes Suggestion #2 Right Side

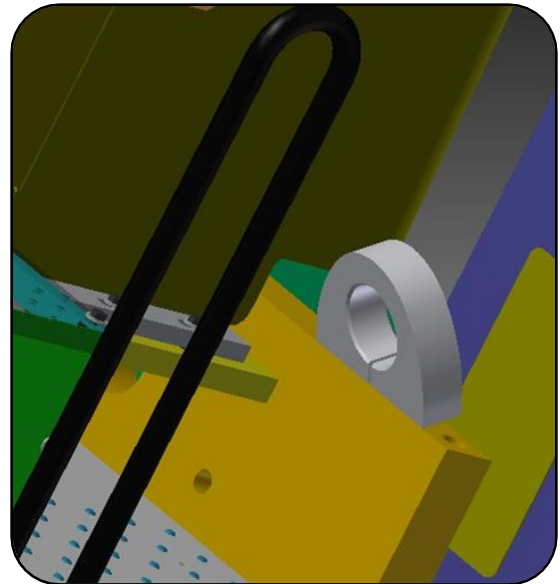


Figure 45: Lifting Eyes Suggestion #2 Left Side

Lifting Eyes Suggestion #3

Suggestion #3 consisted of attaching one of the lifting eyes on the top of the frame on the left side, but flush with the frame (Figure 46). It is important to mention that the lifting eyes do not have to precisely mirror each other. The large size of the machine makes a slight difference in placement on each side negligible.

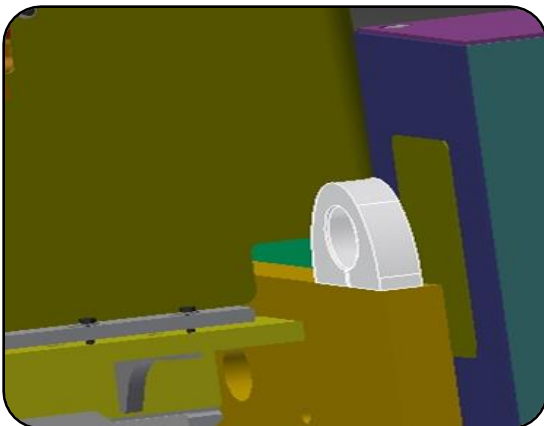


Figure 46: Lifting Eyes Relocation Suggestion #3
(View A)

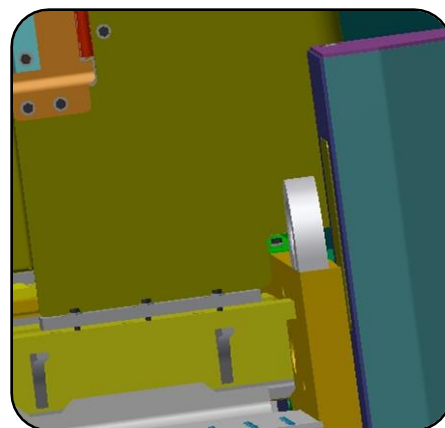


Figure 47: Lifting Eyes Relocation Suggestion #3
(View B)

4.4 Summary

In this chapter, we have explained our design process. We have also provided all of the designs and concept designs that the team generated. In the next chapter, we evaluate each design to determine its usefulness to Caterpillar.

Chapter 5: Evaluation

In order to choose which designs were the best, it was necessary to implement an evaluation system. Specifically, a system that would allow the team to easily compare all the designs against the sponsor and team criteria was important. Therefore, research was conducted on the topic and several methods such as case studies, performance test, interviews questionnaires, and surveys were found. However, all of them faced the same problem, how to transform qualitative data into quantitative data and not lose any information in the process. After more research, it was determined that the House of Quality was the best evaluation method available for this project.

5.1 House of Quality

House of Quality is an evaluation system used by several large companies such as General Motors, AT&T, HP, and Ford. It is used to improve the design of many products including home appliances and construction equipment. The House of Quality method is pervasive in industry because “the foundation of the house of quality is the belief that products should be designed to reflect customer’s desires and tastes,” as stated by Professor John R Hauser in his article titled “The House of Quality,” featured in *The Harvard Business Review Magazine*. This method also allows companies to identify key improvements to develop existing products or to compare current and new products. The team chose this method for its flexibility and reliability. By evaluating our designs with this method, the team would guarantee that the designs were assessed in the most professional and efficient way possible (Clausing and Hauser).




The House of Quality consists of a matrix that relates both what the customer expects from the product, and the engineering requirements necessary to satisfy those expectations. Essentially, the method helps designers to ask: what does the customer want? Why does the customer want this? How will the company satisfy that need? Therefore, the design team can create products or designs that are more beneficial to the customer. In addition, by arranging the data in a structured way, it is easy to conclude what can and cannot be done to satisfy the customer needs.

The evaluation process consists of three initial steps. William Singhose and Jeff Donnell explain in a simple and detailed way these three steps in their book, *Quality: perception of the value of your product - Design, Conformance and Performance*. The three steps are creating a customer needs list and an engineering requirements list, finding the relationships between these requirements, and rating the importance of the customer needs.

The first step entails creating a list of customer needs that must be met by the company/manufacturer. These needs are essentially what the customer wants out of the product or why they choose this specific product; thus, they are often called the “whats” of the design. Most frequently, this list is obtained through user surveys, interviews, or focus groups. For this project, the team created the list based on interviews with our sponsor and by adding our own challenges. These needs were generated using Caterpillar as our primary customer, but we also utilized Caterpillar’s perspective on their customer needs to generate the other requirements for our secondary customer. The customer requirements are as follows: accessibility, space optimization, no interference, safety, quality and material reduced. We chose these requirements as they encompassed all of Caterpillar’s needs, and all of their customers’ needs. These secondary customers are the companies who buy Caterpillar machines.

Once the list of customer needs has been created, the next step is to generate a list of engineering requirements needed to satisfy the customer’s needs. These are how the design team will satisfy these needs; they are also called the “hows” or the quality characteristics that are important to the producer, rather than the customer. For this project, some of the requirements from Caterpillar were placed in the engineering requirements section. Additionally, the team used some of the extra criteria that were brainstormed to add to Caterpillar criteria. The technical requirements are: innovation, total amount of material in the design, structural strength, manufacturing cost, meeting Caterpillar standards (ISO 2867), and simplicity of the design.

The second step is to complete the matrix that will allow the company to see the relationships between the customer needs and the engineering requirements. As seen in Figure 48 the customer needs make up the vertical list on the left, while the engineering requirements

form the horizontal list on top. The matrix is completed by filling each square with symbols that determine the level of correlation between the need and requirement. Each symbol represents a numerical value, being those with a strong relationship  (9), a moderate relationship  (3), and a weak relationship  (1). Figure 48 shows the matrix completed for the criteria chosen by the team.

		Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	X	▲	▼	X
Relative Weight	Weight / Importance	<div>Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")</div> <div>Demanded Quality (a.k.a. "Customer Requirements" or "Whats")</div>	Innovation	Total amount of material	Structural Strength	Simplicity of design	Manufacturing cost	Meet CAT standards
15.0	0.2	Accessibility	○	○	▲	○	○	○
5.0	0.1	Space optimization	○	○	○	○	○	○
25.0	0.3	No interference	○	○	○	○	○	○
25.0	0.3	Safety	○	○	○	▲	▲	○
15.0	0.2	Quality	○	○	○	○	○	○
15.0	0.2	Material Reduced	○	○	○	○	○	○

Figure 48: House of Quality - Customer's needs & importance, and Eng. Requirements,

Furthermore, on the left side of the customer requirements there are two columns: weight/importance and relative weight. These columns are one of the most important parts of the House of Quality method. The customer must weight each criterion as a percentage of how important the criterion is to the whole product, so that all the weights add up to 100%. It is important to mention that the numbers shown in the relative weight column represent percentages. However, the weight/importance the same percentage is shown as a decimal so that the weight/importance column adds up to one.

As customer insight in the design stage is crucial to producing a quality and marketable product, the House of Quality evaluation system is an efficient and useful system. When combined with the other positive attributes of the House of Quality, it can provide managers

and producers an easy way to keep track of their designs, but it is also a tool to bring the design team together to create quality products.

5.2 Evaluation of Designs

In this section, the designs are evaluated using the House of Quality method explained above to determine the combination of designs that best meet the customer requirements. To do so, we established our list of customer requirements, their importance to the customer, the engineering requirements, and the correlation between the engineering and customer requirements, as seen in Figure 48 (above). After those steps are completed, we generate three different sets of values. First, we find the relative weight of each customer requirement. Second, we generate the competitive analysis. Third and finally, we produce the final scores.

Max Relationship Value in Column	9	9	9	9	9	9
Weight / Importance	660.0	420.0	510.0	460.0	460.0	900.0
Relative Weight	19.4	12.3	15.0	13.5	13.5	26.4

Figure 49: House of Quality – First set of calculations

Once we have determined the relationship between each customer and engineering requirement, the software generates the first set of calculations required to determine the best designs. The results of these calculations for our House of Quality can be seen in Figure 49. The first row, Max Relationship Value in Common, represents the maximum value given to the relationship between the customer's requirements and the engineering requirements. The second row, Weight/Importance, represents the calculations of multiplying each correlation column value times its relative weight (Figure 48), and the adding all the results up. The third row, relative weight, represents the calculations of multiplying each correlation column value times its weight/importance (Figure 48), and summing those values. It is important to mention that this value is a percentage.

Once these calculations are completed, we needed to rate our designs on a scale from 0 (worst) to 5 (best). We proceeded to ask our sponsor to consider the performance of the designs in fulfilling their requirements. Table 7 (below) shows the score of each design in each customer requirement category. These ratings make up the competitive analysis and were obtained through the input of the sponsor and the team. We can observe a graph of the competitive analysis on the right, which allowed the team to better see how the designs measured up to one another.

	Red Piece Solution 1	Red Piece Solution 3	Left Side Solution 2	Left Side Solution 3	Left Side Solution 4
Accessibility	0	0	5	3	5
Space Optimization	3	5	5	4	5
No interference	5	5	5	5	5
Safety	0	0	4	3	4
Quality	4	5	3	5	5
Material Reduced	3	5	4	4	3

Table 7: Scores of Designs

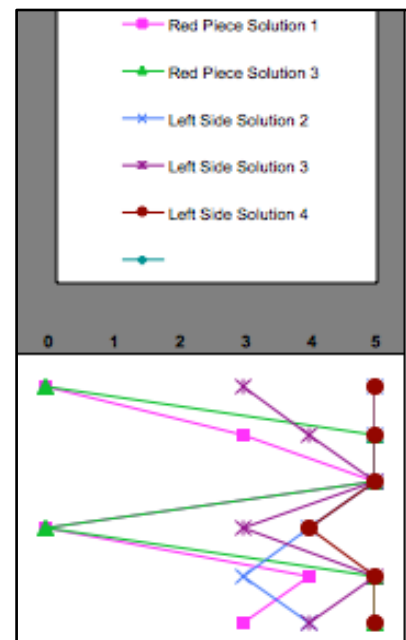


Figure 50: Competitive Analysis

In the subsequent sections, we explain in more detail the reasoning behind each score. Where sponsor input was scarce, the team assumed the role of the customer in evaluating the designs. After the justification of each score, we explain the final calculation and which designs we felt best met our customer criteria.

Red Piece Evaluation

We only evaluated Solutions 1 and 3 for the red piece, as Solution 2 involved mixing two parts that were manufactured differently. Red Piece Solution 1 involved moving the red piece inside the toolbox to avoid interference with a new section of the frame. Red Piece Solution 3 involved creating a smaller piece to fit underneath the new section of the frame. Now we will more fully explain each score each of the red piece solutions received.

In terms of Accessibility, this piece does not affect how accessible the toolbox is, thus it received a score of 0 as it was not applicable. As the toolbox with Solution 1 had less volume than the toolbox with Solution 3, Solution 1 received a score of 3, while Solution 3 earned a score of 5. Both designs solved the interference within the toolbox, thus both solutions obtained a score of 5. In terms of safety, this part does not have anything to do with the safety of the toolbox or the operation of the machine; thus, both designs got a 0, again for not applicable. For quality, we determined this factor based on how well the design exceeded the other customer specifications and met safety standards. For the Red Piece solutions this meant that Solution 3 secured a score of 5, as it provided the largest toolbox with the least material. Solution 1 received a score of 4 in this category. In terms of Material Reduced, Solution 1 reduced material used by 10.8%, thus it received a score of 3. Solution 3, however, obtained a score of 5, as it reduced the material needed for manufacturing by 52%. After we completed the assessment of the Red Piece Solutions, we had to complete the competitive analysis with the Left Side Solutions.

Left Side Evaluation

For the left side, we evaluated Solutions 2-4, as Solution 1 did not meet the ISO standards for stairs and handrails. Solution 2 entailed removing the front and top of the empty box and using it as a stair to get to the cab. In Solution 3, the entire empty box was removed, and a ladder replaced the steps. Solution 4 removed the entire empty box, and the handrail was moved to the right side of the battery box, which was used as a step.

Now that we have been reminded of the designs, we will explain the score of each design in each category. In terms of Accessibility of the cab, Solutions 2 and 4 were found to be equally and highly accessible; thus, these designs earned a score of 5. Solution 3 was found to be about half as accessible, and was given a score of 3. For space optimization, Solutions 2 and

4 again utilized space most effectively and received a 5 in this category. Solution 3 received a score of 4, as this design barely used the space provided less effectively. All of the designs acquired a score of 5 as none of the designs involved any interference. The safest designs were Solutions 2 and 4, as they involve wide, self-cleaning steps to gain access to the cab. Solution 3 received a score of three, as the ladder was small and the steps were narrow, and, though in accordance with the safety standards, could be better improved to provide safer access to the cab. In terms of Quality, we scored this based on how well we exceeded customer expectations. Thus, Solution 2 received a three, because the design merely satisfied the requirements. Solution 3 and 4, however, reduced more material and utilized space in a similar ratio. In terms of material reduced, Solution 2 reduced 47.43% of material, and thus received a score of 4. Solution 3 reduced approximately 44%, and also received a score of 4. It is important to mention that this is an approximation, since we can remove other parts of the handrail that we were not provided a model of; thus, we can only report how much we know we can reduce. Solution 4, on the other hand, requires 43.82% of material in the original design; therefore this solution received a score of 3.

Best Designs

After we scored each design, we proceeded by performing the last calculations that would provide the team each design's score in order to choose the best designs. By multiplying the relative weight row values (shown in Figure 49) by each design column in Figure 50, we generate the relative scores for each design in that category. Once these values were generated, as seen in Figure 51, the results were summed in order to obtain the final score of each design for comparison.

	Red Piece Solution 1	Red Piece Solution 3	Left Side Solution 2	Left Side Solution 3	Left Side Solution 4
	0.0	0.0	75.0	40.5	132.0
	58.2	61.5	75.0	54.0	132.0
	97.0	61.5	75.0	67.5	132.0
	0.0	0.0	60.0	40.5	105.6
	77.6	61.5	45.0	67.5	132.0
	58.2	61.5	60.0	54.0	132.0
TOTAL	291.0	246.0	390.0	324.0	765.6

Figure 51: House of Quality - Second set of calculations

It is evident from these scores that, for the red piece, Solution #1 best fits Caterpillar's criteria. Additionally, it is important to mention that the score difference between both designs is only 45 points, which is relatively small comparative to the left side design margins. Regarding the left side solutions, Solution #4 received the highest score of 765.6 points, nearly twice the score of the next closest design.

The selected designs are shown in Figures 52 and 53, demonstrate that the team reached its goal of reducing material, and, therefore, reducing cost of the battery box. When combined, the designs reduce material by 41.37% in total, which translates into revenues for Caterpillar.

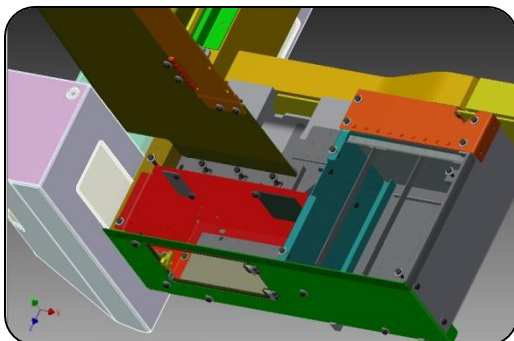


Figure 52: Red Piece Solution #1

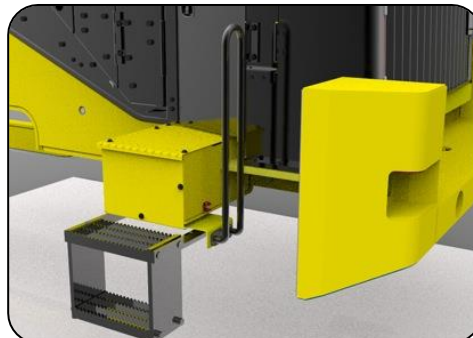


Figure 53: Left Side Solution #2

In addition, we would like to point out that if we had only evaluated the designs based on the material reduced, the outcome would have been different. In that case, Red Piece Solution #3 and Left Side Solution #2 would be the most appropriate. Together, these designs would save about 50% of the total material.

Material Based Suggestion				
Solutions	Original	New	Saved	%
Right Side #3	742,105.00	256,688.40	485,416.60	65.41
Left Side #2	4,290,378.70	2,255,374.16	2,035,004.54	47.43
Total	5,032,483.70	2,512,062.56	2,520,421.14	50.08

Table 8: Most Material Reduced (in mm-cubed)

Chapter 6: Recommendations and Conclusions

In this chapter, we discuss our recommendations for Caterpillar and the conclusions drawn from our project. After evaluating our designs, we chose the best designs to recommend to our sponsor. In addition, we make recommendations in terms of future studies.

6.1 Recommendations

We recommend that Caterpillar implements Red Piece Solution #1 and Left Side Solution #4, as it will most benefit their customers and other needs. However, they might choose to use material reduced as their only evaluation system for our designs. In that case, Caterpillar may choose to use Red Piece Solution #1 and Left Side Solution #3.

Our contributions to Caterpillar, Inc. have been to provide cost reducing solutions to this redesign, to give Caterpillar some new and out-of-the-box ideas, their engineers can build on, in order to achieve a better and improved design.

For future studies, we recommend looking into changing the toolbox style to allow for more material and cost reduction. We also recommend looking into different materials that have an extremely high melting point and are cheaper than steel for the Steel Mill Application 980H2.

6.2 Conclusion

We achieved our goal of redesigning the battery box to reduce the cost and solve the interference. To do so, we gathered our design specifications and discovered an evaluation system that allowed us to take all necessary criteria into account. Several designs and redesigns were created based on our sponsor's feedback. We evaluated our designs, and then recommended our designs to Caterpillar based on our evaluation. Finally, we delivered several suggestions for the relocation of the lifting eyes.

Overall, this project will benefit our sponsor Caterpillar. We have provided several new ideas for the redesign of the battery box and relocation of the lifting eyes. Caterpillar, Inc. can utilize these designs to help further their design process as they redesign the 980H2 Steel Mill machine. In addition, all of the designs we offer in this report show a reduction in material, and, therefore, a reduction in cost. This benefits Caterpillar, as the Steel Mill Application machine has a considerably higher cost from the added protection on the machine. Reducing the cost in

every way possible helps to prevent the cost of the machine becoming too high for customers to buy, or too high for the company to use the machine as a profit generator. We hope that our work helps Caterpillar to create the final battery box design for the machine.

In addition, the team members learned a great deal about industry and communication from this project. This helped to teach us all about real-world design problems and how to communicate with professional engineers. This is a skill that will be required of us all as we enter industry. The team learned a great deal about another form of communication as well: cross-cultural, inter-group communication. This was a challenge that we all faced daily. Throughout the project, the team had to learn to come together to reach our goal despite academic, language, and cultural differences. Through our collaboration, the WPI students became more literate in Chinese culture and learned more about how to communicate their ideas in the simplest way to be easily understood. The HUST students were able to practice their English and presentation skills, but they also learned how to communicate with a very diverse team of foreigners. Collaboration between the HUST and WPI students created an environment for the students to learn the most from each other, both in a cultural and professional way.

In conclusion, everyone benefitted from this project: Caterpillar, WPI, HUST, and the students themselves.

Chapter 7: Reflective Essays

7.1 Discussion of Design

During this project, the team focused in redesigning the Battery Box of the 980H2 Steel Mill Wheel Loader for Caterpillar Inc. Additionally an evaluation system to compare and choose the best design, was developed.

In order to redesign the Batter Box, the team first developed a design strategy that would allow the design process to be more structured and efficient. First, the design process was divided into right and left side of the machine. For the Right Side the team focused in solving the interference inside the toolbox between a red piece and the main frame of the machine. In order to solve the mentioned interference the team developed 3 designs. Since one of the goals of the project was to reduce cost, the team as well came up with four designs for the toolbox door, and handrail respectively. On the other hand, the left side redesign of the machine faced a different approach. Since the left side did no longer have a toolbox due the removal of the tilt group mechanism to operate the hood, the team had more freedom in terms of designs. Therefore, 4 ideas were devolved to reduce cost, without compromising safety and quality. Unfortunately, after receiving feedback from our Caterpillar contact the team learned that some of their designs were not feasible or met the ISO 2867 standard. Additionally, the team learned that there was no handrail on the right side of the machine; therefore it made no sense to create one.

Once the designs were created and approved by our Caterpillar contact, the team proceeded to evaluate them. First, we discerned the most important factors to Caterpillar and their customers from our initial meeting with our sponsors in Suzhou, China. We found that the two criteria most important to Caterpillar are reducing cost and meeting customer needs. When the team looked more closely at these criteria, we found a few areas to focus on and metrics with which to measure our progress.

First, in cost reduction we focused on the manufacturing cost. While we cannot know precisely how much a new design would cost to redesign, from the background knowledge of the Industrial Engineers in our team, we can make assumptions as to what would be more costly to produce. The metric we decided to use was the percentage of the mass of material

reduced. In addition, we emphasized simplicity and relation to the old design so as to reduce the cost of manufacturing.

Second, to meet all of the customer needs, we found that there were several additional standards the design should meet. The toolbox must be functional, meaning that there should be no way for the tools to fall out and no interference between the door and other parts of the machine. The customer is also concerned with safety, thus any changes to the stairs that lead to the cab must comply with the standards set out in ISO2867 and should make climbing to the cab easy.

After looking at these criteria, the team came up with our own criteria that we wanted to meet to try to create the best design possible. Space optimization is important to us so that we give Caterpillar and their customers a machine that takes the smallest spaces, but makes valuable use out of it. To measure this we will look at the usable space in the old design and compare it with the area of usable space in our designs. Subsequently, we decided that innovation was important to the design. However, measuring innovation is mainly subjective, thus this metric will be determined by how innovative the team feels the final design is. The last measure that the team came up with was quality. We felt that quality is one of Caterpillar's main selling points for their products from looking at their website. The metric we decided that this would be whether or not we met the ISO standards.

From these performance metrics, we found that we also needed a more concrete evaluation system to incorporate the importance of each criterion and also the relationship between them. The team conducted research and used knowledge of past Industrial Engineering principles to find different evaluation techniques. We considered a simple weighted grading system, where Caterpillar would provide a percentage out of 100 for each criterion, which would then be multiplied by the score for each criterion. However, the team decided that this did not adequately represent the relationships between customer needs and other important aspects of the design. In our research, we found the House of Quality to be an evaluation system, which represents the weights of each design aspect and customer needs and the relationship between the design constraints and metrics. Thus, we chose the House of Quality as our evaluation system method (figure 1). This method helps engineers and designers

to ask: what does the customer want? Why does the customer want this? How will the company satisfy that need? Therefore, the design team can create products or designs that are more beneficial to the customer. In addition, by arranging the data in a structured way, it is easy to conclude what can and cannot be done to satisfy the customer needs.

The evaluation process consists of three steps. William Singhose and Jeff Donnell explain in a simple and detailed way these three steps in their book, *Quality: perception of the value of your product - Design, Conformance and Performance*. The three steps are creating a customer needs list and an engineering requirements list, finding the relationships between the lists, and rating the importance of the customer needs.




The first step consists of creating a list of customer needs that must be met by the company/manufacturer. These needs are essentially what the customer wants out of the product or why they choose this specific product; thus, they are often called the “whats” of the design. Most frequently, this list is obtained through user surveys, interviews, or focus groups. For this project, the team created the list based on interviews with our sponsor and by adding our own challenges. Once the

list of customer needs has been created, the next step is to generate a list of engineering requirements needed to satisfy the customer’s needs. These are how the design team will satisfy these needs; they are also called the “hows” or the quality characteristics that are important to the producer, rather than the customer. For this project, the team used some of the extra criteria that were brainstormed to add to Caterpillar criteria. Additionally, some of the requirements from Caterpillar were placed in t

The second step is to complete the matrix that will allow the company to see the relationships between the customer needs and the engineering requirements. As seen in Figure 2 the customer needs make up the vertical list on the left, while the engineering requirements

		Column #					
		Direction of Improvement: Minimize (▼), Maximize (▲), or Target (X)					
		1	2	3	4	5	6
Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")					
		Innovation	Total amount of material	Structural Strength	Simplicity of design	Manufacturing cost	Meet CAT standards
15.0	0.2	○	○	▲	○	○	○
5.0	0.1	○	○	○	○	○	○
25.0	0.3	○	○	○	○	○	○
25.0	0.3	○	○	○	▲	▲	○
15.0	0.2	○	○	○	○	○	○
15.0	0.2	○	○	○	○	○	○

Figure 54: House of Quality - Customer's needs & importance, and Eng. Requirements,

form the horizontal list on top. The matrix is completed by filling each square with symbols that determine the level of correlation between the need and requirement. Each symbol represents a numerical value, being those with a strong relationship  (9), a moderate relationship  (3), and a weak relationship  (1).

Additionally in Figure 2 the team's determination of the customer and engineering requirements are shown. The customer requirements are as follows: accessibility, space optimization, no interference, safety, quality and material reduced. The technical requirements are: innovation, total amount of material in the design, structural strength, manufacturing cost, meeting Caterpillar standards (ISO 2867), and simplicity of the design.

Finally, on the left side of the customer requirements there are two columns: weight/importance and relative weight. These columns are one of the most important parts of the House of Quality method. As the customer has to determine the importance of each requirement, this factors in with the relationships to generate how important each factor is relative to one another. It is important to mention that the numbers shown in the relative weight column represent percentages. However, the weight/importance the same percentage is shown as a decimal so that the weight/importance column adds up to one. In this last step, it can be observed why the House of Quality is such an efficient and trust worthy system. Because of the system's ability of analyzing the quantitative and qualitative part of the data, and most important the customer's insight regarding what aspect of the product is more important for him, the system is able of providing managers not only with a final product to manufacture, but as well a tool to bring together engineers, designers, marketing representatives and the customer.

7.2 Discussion of Constraints

The main constrain our project faced was the design limitation. At the beginning of the project, the team understood that there was complete freedom in terms of designs. That idea disappeared later when the team visited Caterpillar Inc. for a second time. During that visit the team learned that Caterpillar manufactures 10 980H2 Steel Mill Wheel Loaders per year, therefore they wanted to see small and cost effective changes or improves to designs. As a result, the team realized that they could not redesign the right side toolbox door, nor apply one of the solutions to the internal interference between the read piece and the main frame. Additionally, the team was not allowed to change any of the materials of the machine in order to reduce cost. Lastly, the team was never provided with an accurate price formula in order to calculate the monetary representation of the material reduced. Therefore, in order to demonstrate the monetary value, the team used percentage of material reduced. Although the designs constrains were learned halfway through the project, the team was able of implementing the feedback gained and proceeded to develop better designs that would satisfy and meet Caterpillar's specifications.

7.3 Discussion of Lifelong Learning

In this section, Pedro and Murtada will discuss their own individual experiences in completing this project.

Pedro Escuer:

In general the project was a challenge, both on the professional and personal side. On the professional side, the challenge was understanding each other. Our Chinese partners' English was good, but we as a team had some problems explaining our ideas. In my case I learned that English is not the only language you can use to communicate and express your ideas. We used shoeboxes to illustrate how we could redesign the door of the toolbox, drawings and even straws when discussing the handrails. Another professional challenge was the different approach we all took in order to solve the problem. WPI students (Industrial Engineers & Management Engineer) focused more in finding the most cost effective solution, while the HUST students (Mechanical Engineers) were more interested in the design itself of the ideas, demonstrating the difference between majors. Regarding the personal challenges I faced, I can say that I had an idea of what was China going to be, but once I got there I realized

it was a whole new world. Everything is so different, that it can be overwhelming. I like to think that life is full of challenges and this experience was one I am lucky to have had the opportunity of taking. During my time in China I grew both professionally and personally. By working with people from different backgrounds cultural (Saudis, Chinese, and American) and professional (Mechanical Engineers), I learned how to work in an efficient and respectful way with people, regardless of their background or language. I learned how to adapt myself to a place where everything challenges you, from the food, to crossing the street. I learned to appreciate the culture, to learn from our differences, and have a better understanding of China in general. After my time in China I can say I feel confident saying that I achieved the main goal of WPI's Global Perspective Program, to create engineers with a multicultural background and professionals able of solving problems under different cultural conditions.

Lastly, in order to continue my learning endeavor I plan to find an operations/logistics rotational program that allows me to travel around the world, learning more and more of every culture and place I go to, in order to build on the knowledge gained in my previous experiences as China and Australia.

Murtada Al Darweesh

Being in a different part of the world gives a good opportunity to learn more about business and experiencing different work environment and interacting with multinational people. This opportunity was a valuable experience for future career. The project was mechanical problem, which was somehow far from an industrial view. However, this taught us how to involve in different department work and distinguish things together as a team.

This project provides us an opportunity to work with a team from different culture and different background. This allows us to experience the ability of working in different environment with different people. The most valuable gain of this project is the learning experience of to work in new conditions. Personally, I gained a lot from this project.

This project improved my educational skills as well as the working experience. I used my skills as an Industrial engineer to provide solutions for a mechanical design. These solutions have to meet the criteria of the design. The design must meet the requirements of company and satisfy customers. I learned how to work these solutions with mechanical engineers. I also

had the opportunity to learn new designing software that helped me understand mechanical problems better. Overall experience working with mechanical engineers was valuable and enjoyable. It is hard to find an opportunity to work with different majors, nationalities, and environment like this project.

Different environment work is an opportunity to learn more about how different business works. I visited our project sponsor company, Caterpillar, with the team. I learned about the company operations and businesses. I also, out of the work time, visited several branches of the company, SABIC, that sponsor me from Saudi Arabia. I learned a lot of how China industry improving and interacting with the world industry. I got a job offer from the branch in China. This was one of the advantages I have of being in the China center project. I had a wonderful experience that I appreciate.

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Appendix A: House of Quality

Title: _____

Author: _____

Date: _____

Notes: _____

